PROOF-OF-CONCEPT MESOSCALE DISCUSSIONS FOR SHORT-TERM WILDFIRE PREDICTION ON THE SOUTHERN GREAT PLAINS

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1. INTRODUCTION

Damaging wildfires synthesize anomalous environments characterized by short-lived combinations of vegetative fuels and weather. Mesoscale atmospheric processes and their juxtaposition with high-risk fuels greatly influence the potential for dangerous fire behavior and spread (Werth et al. 2016). Such atmospheric effects on the fire environment are well suited to the application of skillful meteorological mesoanalysis, including the use of short-term predictions aided and informed through use of Convection-allowing Models (CAMs, ≤4 km grid spacing, Lindley et al. 2023).

This paper will highlight efforts by the Southern Great Plains Wildfire Outbreak Working Group (SGPWO WG, Lindley et al. 2021), an online collaborative multi-agency operations-to-research-to-operations community focused on science-based support to state forestry agencies in Texas, Oklahoma, and Kansas, to provide proof-of-concept mesoscale messaging to inform tactical decision making for wildland fire management officials. Analogous to Mesoscale Discussions (MDs) issued by the Storm Prediction Center for evolving convective hazards and notable winter precipitation events, the group posted a total of 56 fire-focused MDs between October 2021 and April 2023. These fire MDs were based on detailed analyses spanning the meso-alpha and meso-beta scales using trends in remote sensing and in situ observational data and the evolution of fire-effective weather features depicted in CAMs relative to antecedent fuel environments. In many cases, fire MDs successfully predicted the onset of problematic wildfire occurrence on the sub-county warning area scale hours prior to new wildfire ignitions. In other instances, life threatening escalations in fire behavior were highlighted prior to the onset of particularly dangerous fire conditions, including in advance of wildfire/wind shift interactions. This information improved situational awareness of imminent fire impacts and informed mitigative actions and services by fire/land managers for problematic and significant wildfires.

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2. WHAT IS MESOANALYSIS?

The Glossary of Meteorology definition of mesoanalysis includes: *"The representation of temperature, moisture, pressure, and wind variations on horizontal scales of 10-100 km. The analysis seeks to define mesoscale features…that can be related to important local and regional circulations that in turn may have a significant impact on local and regional weather systems" (*American Meteorological Society, 2023). The authors propose that a practical operational definition might also include: *"Analysis of the meteorological mesoscale environment through: 1) application of conceptual models to bridge the gap between observations and high-resolution numerical weather prediction, 2) and communication of actionable intelligence on the environmental and meteorological evolution of potentially hazardous weather focused on the 0-6 h forecast period."* Thus, the primary objective of mesoanalysis in operational forecasting is to extend effective messaging of advanced lead time for evolving high-impact and dangerous events.

3. MESOSCALE INFLUENCES ON FIRE

Paraphrasing from several works by Stephen J. Pyne, a renowned author and fire historian, fire is what its circumstances make it. It synthesizes its surroundings. Wildfires become damaging when they burn outside normal constraints and in rare combinations of fuel and weather that are naturally short-lived. Fuel determines whether wildland fire will ignite, but how it spreads and propagates is largely a function of short-term weather (Pyne 2012, 2015, 2019, and 2020).

Further, it has long been recognized that most fire behavior-related wildland firefighter fatalities in the U.S. are the result of mesoscale phenomenon (Chandler 1976). Most modern references to the mesoscale fire-environment have focused on coupled fire-scale numerical modeling (Huang et al. 2009, Nauslar et al. 2018, Hädrich et al. 2021, Mass and Ovens 2021, and others), however, and not near-term prediction of new or escalating wildfire occurrence and behavior.

There are well-known sub-synoptic scale atmospheric patterns and conditions for new fire ignition, problematic spread, and extreme fire behavior on the southern Great Plains. These conceptual models include fire-effective low-level thermal ridges (LLTRs, Lindley et al. 2017) and wildfire/wind shift interactions that promote accelerated fire spread, growth, and megafire development (Lindley et al. 2019). Discussion below will highlight three case examples where mesoanalysis, combined with knowledge of the background environmental fuelscape, permitted short-term predictions of new wildfire ignition and/or escalations in dangerous fire conditions.

4. CASE EXAMPLES

a. 17-18 March 2022

A destructive southern Great Plains wildfire outbreak (SGPWO, Lindley et al. 2014) impacted parts of northwestern and west-central Texas on 17-18 March 2022. The outbreak burned 27,381 ha, destroyed 50 homes and structures, killed one person, and injured two others. The fires occurred in an area characterized by high-fine fuel loading and widespread >90th percentile energy release component (ERC, Bradshaw et al. 1983) per the Wildland Fire Assessment System (WFAS, Jolly et al. 2019). A surface low (998 hPa) centered over northwestern Texas promoted strong downslope westerly winds to its south. The hourly 3 km Texas Tech Real Time Weather Prediction System's Weather Research and Forecasting Model (TTU WRF, Texas Tech Atmospheric Science Department, cited 2023) deterministic Red Flag Threat Index (RFTI, Murdoch et al. 2012) showed the emergence of extremely critical fire weather (RFTI 7-8) on the periphery of the model's RFTI domain over west-central Texas (Fig. 1).

At 19:01 UTC 17 March 2022, a fire MD posted in the SGPWO WG discussion forum outlined an area of west-central Texas and stated *"The risk of additional new fire ignition and conditional significant wildfire potential is now increasing…persisting for the next 4-5 hours. Conditions are now characterized by extremely critical fire weather (RFTIs 7 & 8) along and windward of the LLTR which is now established from near Seymore to Wall to Sonora. This will result in a very favorable environment for dangerous fire behavior considering ambient volatile fuelscape."* By 21:37 UTC, *Geostationary Operational Environmental Satellite-16 (GOES-16)* shortwave IR (SWIR) showed at least six active large wildfires within the previously indicated geographical area (Fig. 2).

By early evening, regional Doppler radars and surface observations showed an advancing cold front rapidly approaching a large fire complex in Eastland County, Texas. At 00:54 UTC 18 March 2022, a subsequent fire MD posted to the SGPWO WG headlined *"…VERY DANGEROUS WIND SHIFT IMMINENT AT EASTLAND COUNTY FIRE COMPLEX… The front is rapidly approaching. A dramatic increase in burn area is likely to occur. The complex of fires could present an imminent threat to life and property in/around Rising Star and Gorman following frontal passage."* Ultimately, a significant loss of homes occurred at Gorman, Texas, and a sheriff's deputy was killed while evacuating the public.

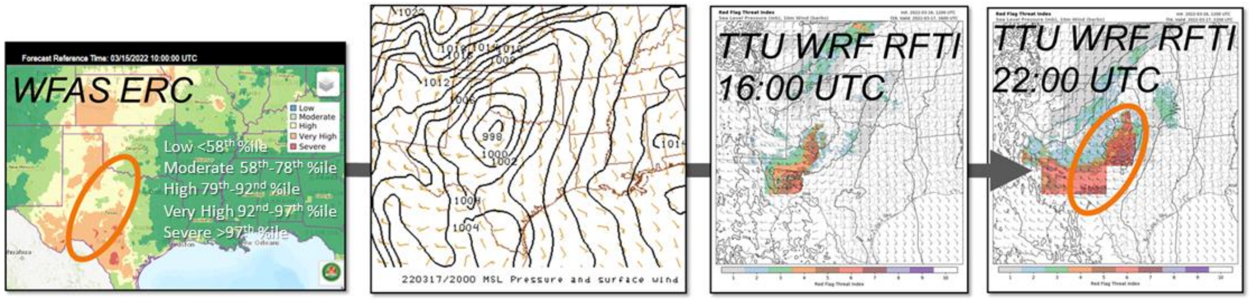

Figure 1: WFAS ERC percentiles (valid 15 March 2022), 20:00 UTC 17 March 2022 mslp and surface wind, 16:00 and 22:00 UTC 17 March 2022 TTU WRF RFTI. Common geography of overlapping high ERCs and intense fire weather indicated (orange oval) in first and last images.

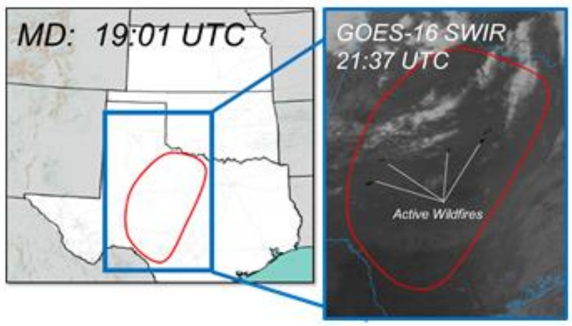

Figure 2: SGPWO WG fire MD issued at 19:01 UTC 17 March 2022 and 21:37 UTC 17 March 2022 *GOES-16* SWIR. Common geography indicated (red oval).

b. 29-30 March 2022

A plains firestorm burned 40,930 ha, destroyed 26 homes and injured three people across four states on 29-30 March 2022. WAFS ERCs were analyzed to be >80th-90th percentile over a broad area of pre-existing above normal fine fuel loading on the southern Great Plains, with the highest values along a narrow corridor near the 100th meridian- the line of longitude that demarks the Texas Panhandle and western Oklahoma state line. Fire-effective conditions developed within this antecedent fuel environment south of a 986 hPa surface low over north-central Kansas. A dryline/surface trough extended south from the low over central Kansas, western Oklahoma, and west Texas. CAMs depicted the evolution of a LLTR west of the dryline, with the exit region of a strong mid-level jet overspreading a highly amplified LLTR from south-central Kansas southward toward southwestern Texas. The 12:00 UTC 29 March 2022 run of the TTU WRF depicted a narrow corridor of critical to extremely critical fire weather (RFTIs 6-7) along this feature by 21:00 UTC (Fig. 3).

By early afternoon several fires were ongoing from southern Kansas, southward to southwest Texas. A predictable mesoscale signal, however, was evident for an escalating high-end wildfire threat in the eastern Texas Panhandle and far western Oklahoma where short-term high-resolution meteorological models showed fire-effective atmospheric features and intense fire weather aligning with volatile fuels. A fire MD posted within the SGPWO WG at 18:46 UTC stated: *"The best alignment of extremely critical conditions is beginning. The LLTR is amplifying along the 100th meridian…The most likely areas for new/significant fire ignition and spread will begin to shift/edge eastward toward the eastern panhandles and far western Oklahoma in the next 0-3 hrs*." Within the hour, a pair of wildfires ignited on either side of the Texas/Oklahoma state line, and by 00:58 UTC 30 March 2022, *GOES-16* SWIR imagery depicted two ongoing >12,000 ha fires (Fig. 4). The Washita River Complex Fire in Roger Mills County, Oklahoma, became particularly damaging and destroyed homes in Durham, Oklahoma.

c. 31 March 2023

Application of mesoanalysis toward the short-term predictive fire environment provided forecasters an opportunity to increase lead time in public messaging prior to a particularly destructive wildfire episode in central Oklahoma. On 31 March 2023, numerous fires burned 5,509 ha and destroyed 226 structures, primarily in the northern Oklahoma City suburbs. It was reported that 36 people received minor injuries in the fires and related evacuations.

The outbreak of fires occurred in moderately fire-receptive fuel conditions, where fine fuel loadings were characterized as near normal along a gradient of ERCs in the 40th to 60th

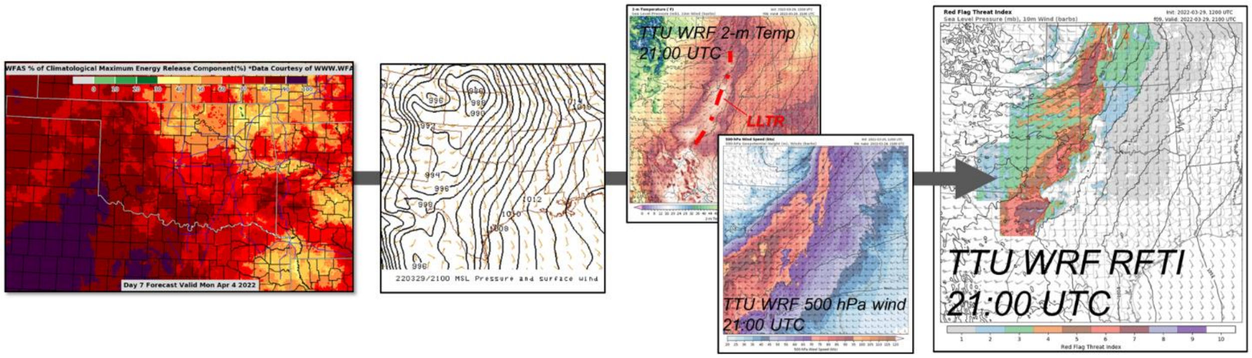

Figure 3: 29 March 2022 WFAS ERC percentiles, 21:00 UTC 29 March 2022 mslp and surface wind, 21:00 UTC 29 March 2022 TTU WRF 2-m temperature and surface wind (LLTR denoted), 500 hPa wind and geopotential heights, and RFTI.

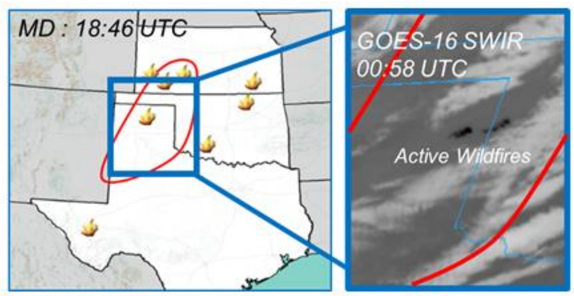

Figure 4: SGPWO WG fire MD issued at 18:46 UTC 29 March 2022 and 00:58 UTC 30 March 2022 *GOES-16* SWIR. Pre-existing fires (flame icons) and common geography (red oval) indicated.

percentile range. Further, light precipitation fell during the preceding overnight and early morning hours over much of south-central and eastern Oklahoma, and established an effective eastward barrier to significant wildfire potential (Fig. 5).

The magnitude of fire weather experienced during the peak diurnal burn period on the 31st was intense, and worked to compensate for the modestly conducive fuelscape. CAMs, including the 12:00 UTC 31 March 2023 TTU WRF depicted coupling of a LLTR and an overspreading mid-level jet (49-51 m s^{-1} at 500 hPa) consistent with fire-effective LLTR conceptual models (Lindley et al. 2017). TTU WRF RFTIs were projected to reach extremely critical to localized historic levels (RFTI 8-9) as these features translated eastward across the state, with fire-favorable conditions maximized around 19:00 UTC in central and northeastern Oklahoma (Fig. 6).

By 17:30 UTC, Oklahoma Mesonet observations showed a corridor of locally very dry air and intense wind gusts developing in proximity to high-resolution model depictions of these features (Fig. 7). At 17:31 UTC a fire MD posted to the SGPWO WG stated: *"RHs* [relative humidities] *are now falling rapidly to 10-20% in the highlighted area, and this trend will continue to advance eastward closer to the advancing LLTR. Extremely critical fire weather will peak in this corridor by 18-20z. New problematic fire occurrence is likely with possible growth of large and locally damaging fires."* A subsequent fire MD update at 18:53 UTC stated: *"New fire starts/ignitions are increasing rapidly…possibly in association with a localized 'blow torch effect'. The potential exists for new fire starts to outpace local jurisdiction resources and for the evolution of damaging/dangerous wildfires."* Both fire MDs (Fig 8) were translated into public-facing mesoscale graphics (Fig. 9) that highlighted areas of increasing wildfire threat, and ultimately, highlighting "Dangerous Wildfire Outbreak Underway." The former of which was issued just more than an hour prior to the onset of fire. By 20:46 UTC, dozens of wildfires were ongoing in the MD-indicated areas.

5. SUMMARY

Mesoscale analysis performed with knowledge of the fire environment (weather and fuels) can inform short-term predictions of new wildland fire ignition and problematic spread/extreme fire behavior. Though demonstrated here with wildfire episodes on the southern Great Plains, these concepts could additionally be applied to the evolution of notable wildland fire processes in the western U.S. and elsewhere, including: the onset of downslope wind storms, west coast thermal troughs, convective outflow, sting jets, pyrocumulonimbi and associated downdrafts and fire generated tornadoes, dry lightning and other fire-related phenomena.

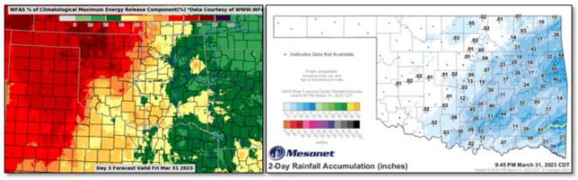

Figure 5: WFAS ERC percentiles and Oklahoma Mesonet 2-day rainfall, both valid 31 March 2023.

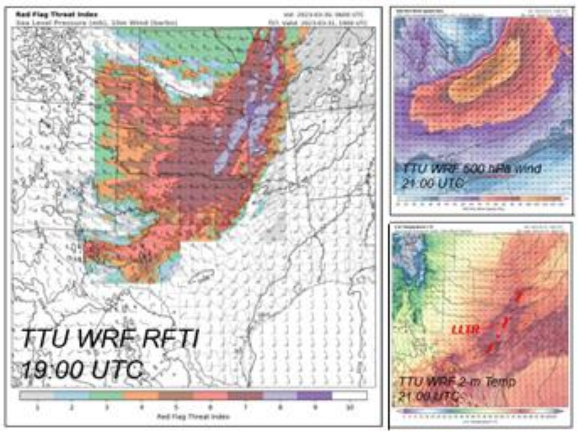

Figure 6: TTU WRF RFTI valid 19:00 UTC and 21:00 UTC 21:00 UTC 31 March 2023 2-m temperature and surface wind (LLTR denoted bottom right), and 500 hPa wind and geopotential heights (top right).

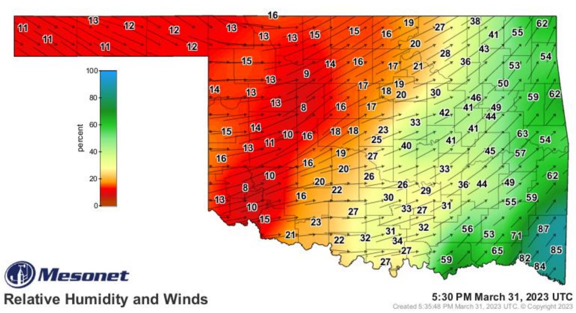

Figure 7: Oklahoma Mesonet 2-m RH and 10-m winds at 17:30 UTC 31 March 2023.

The Deputy Chief of Fire Operations at Oklahoma Forestry Services (OFS), Drew Daily (personal communication 2023), stated: *"mesoscale discussions have proven to be a valuable input for us at OFS. The MDs assist us by maintaining a forward lean to preparedness while focused on immediate fire operations. The real time fire environment snapshot is invaluable for maintaining sound situational awareness at all levels – from the firefighter on the ground to the agency heads that are supporting operations."*

The proof-of-concept fire MDs shown here demonstrate that short-term mesoscale predictions of new fire occurrence and trends in

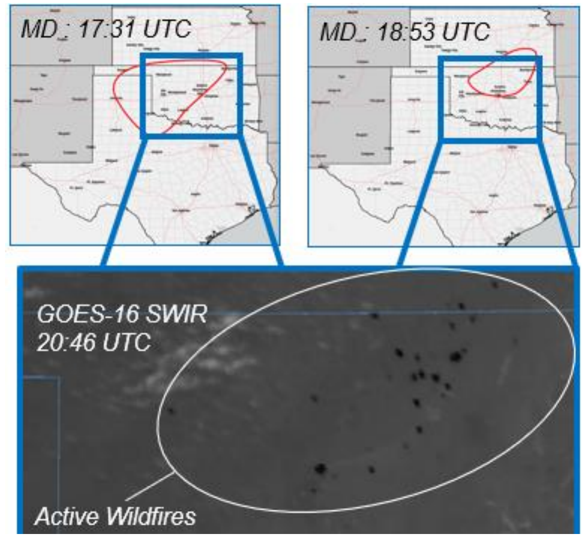

Figure 8: SGPWO WG fire MDs at 17:31 and 18:53 UTC and GOES-16 SWIR at 20:46 UTC 31 March 2023.

Figure 9: Public-facing mesoscale messaging graphics from WFO Norman on 31 March 2023.

existing fire behavior are possible. The authors advocate for greater operational efforts to provide such services. There are inherent fire-scale predictive limitations in forecasting the exact location and timing of new wildfire starts, largely due to the anthropogenic component of many ignitions. The fire environment, however, is predictable. Hence, so is fire's propensity for ignition, problematic spread, and extreme behavior when favorable vegetative fuel and weather conditions align on short time scales and over small geographic areas. Regardless of ignition source, notable fire incidents will not evolve unless both weather and fuels are supportive (Pyne 1982). Thus, while the occurrence of any particular fire is difficult to predict with specificity, forecasting the limited spatiotemporal existence of anomalously fire-effective conditions that support dangerous wildfire occurrence is indeed possible. It is incumbent for meteorologists and fire analysts to work across multidisciplinary jurisdictions in order to develop expertise in short-term predictions of the fire environment useful in fire service operations.

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